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Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE January 28, 2002	3. REPORT TYPE AND DATES COVERED 15/APR/98 – 30/SEP/02
4. TITLE AND SUBTITLE Modeling of Radiation from High Temperature Chemically Reacting Flows		5. FUNDING NUMBERS DAAG55-98-1-0236
6. AUTHOR(S) Deborah A. Levin		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Pennsylvania State University, Department of Aerospace Engineering, 233 Hammond Bldg., University Park, PA 16802		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U. S. Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709-2211		10. SPONSORING / MONITORING AGENCY REPORT NUMBER P-38700.8-EG-SDI

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13. ABSTRACT (Maximum 200 words)

The interaction of a jet from a 60-lbf thruster positioned on the side of a small rocket, using the direct simulation Monte Carlo method (DSMC) was applied to model the three-dimensional jet-atmosphere interaction. Chemical reactions between free stream and plume species were included in the simulations. Altitudes of 80 to 160~km and velocities of 3, 5 and 8 km/sec were considered. Chemical reactions between free stream and plume species were included in the simulations. Both uniform and non-uniform conditions were used at the thruster exit. A Navier-Stokes solver was used to calculate flow inside the thruster and in the near field of the plume. A two-stage DSMC numerical strategy was then used to calculate the plume, with sequential computations of an axisymmetric plume coreflow and three-dimensional plume-freestream interaction. The impact of rocket velocity and altitude on the plume-atmospheric interaction in terms of species produced by chemical reactions that can contribute to UV and MWIR radiation was examined. The UV radiation due to the NO and OH species has been computed and is sufficiently high such that an imager filtered to the 250 and 310 nm pass bands would be able to detect this radiation. These methodology is now being applied to generic cases related to the Miniaturized Kill Vehicle (MKV).

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1) List of Manuscripts:

Gimelshein, N.*, D.A. Levin and S.F. Gimelshein*, “Numerical Analysis of OH Product Mechanisms in a Hypersonic Flow at High Altitudes,” (Contributing Author, Supervised Lead Author), Accepted to the AIAA Journal, Jan 31, 2002. – peer reviewed

Gimelshein, N. E.*, Gimelshein, S. F., and D. A. Levin, “Vibrational relaxation rates in the direct simulate Monte Carlo method,” Physics of Fluids, December 2002, Vol. 14, No. 12, pp. 4452-4455.. (Contributing Author, Supervised Lead Author)

Manuscripts in preparation:

Benson, C.M.*, S. Gimelshein*, D. Levin, and A. Montaser, “Consideration of Coalescence in a Direct Simulation Monte Carlo Aerosol Model,” to be submitted to *Spectro-chimica Acta*., (Contributing Author, Supervised Lead Author)

D. Levin , Benson, C.M.*, S. Gimelshein*, and A. Montaser, "An Advanced Model for the Determination of Aerosol Droplet Lifetime in a High-Temperature Environment,” currently being prepared for the Journal of Fluid Mechanics (Principal author).

2) List of Conference Papers:

Benson, C.M.*, S. Gimelshein*, D. Levin, and A. Montaser, “Modeling of Droplet Evaporation and Coalescence for Direct Injection into an Inductively Coupled Plasma,” AIAA Paper No. 2001-3037, 35th AIAA Thermophysics Conference, Anaheim, CA, June 2001.

Gimelshien, N., D. Levin+, F. Gimelshein, “Numerical Modeling of OH Production in High-Temperature Rarefied Flows With the DSMC Method,” AIAA Paper No. 2001-2892, 35th AIAA Thermophysics Conference, Anaheim, CA, June 2001.

Gimelshein, S., Alexeenko, A, and D. Levin, +“Modeling of Chemically Reacting Flows from a Side-jet at High Altitudes,” *AIAA Paper No. 2002-0212*, 40th Aerospace Sciences Meeting & Exhibit, NV, January 2002.

Gimelshein, S., Levin, D., Markelov, G., Kudryavtsev, and Ivanov, M., “Statistical Simulation of Laminar Separation in Hypersonic Flows: Numerical Challenges*,” AIAA Paper No. 2002-0736,* 40th Aerospace Sciences Meeting & Exhibit, NV, January 2002.

Levin, D.+, Benson, C., Gimelshein, S., and A. Montaser, “Simulation of Droplet Heating in an Inductively Coupled Plasma,” , Paper No. 2C03, 2002 IEEE International Conference on Plasma Science, May 2002, Banff, Alberta, Canada.

Benson, C. M., Zhong, J., Gimelshein S., Levin, D.,+ “A General Model for the Simulation of Aerosol Droplets in a High-Temperature Environment*,” AIAA Paper No. 2002-3181*, 32nd AIAA Fluid Dynamics Conference, June 2002, St. Louis, Missouri.

Gimelshein, N., Gimelshein, S., Ivanov, M., D. Levin+, Wysong, J., “Reconsideration of DSMC Models for Internal Energy Transfer and Chemical Reaction,” 23rd International Symposium on Rarefied Gas Dynamics, 21-25 July 2002, Whistler, British Columbia, Ca.

Benson, C., Gimelshein, S., Levin, D.+, and Montaser, A., “A Direct Simulation Monte Carlo Model for the Determination of Aerosol Behavior in a High-Temperature Enviornment,” 23rd International Symposium on Rarefied Gas Dynamics, 21-25 July 2002, Whistler, British Columbia, Ca.

3) Scientific Personnel:

Deborah A. Levin, Sergey Gimelshein, Robert Collins, Craig Benson, Alina Alexeenko, Natalia Gimelshein, Jianqiang Zhong.

4) Scientific Progress and Accomplishments:

The following specific conclusions were obtained from the two-phase flow modeling research:

1. A computer model has been constructed to determine the spatial distribution of liquid aerosols in high-temperature gas environments. The model is based on a DSMC particle simulation technique that enables the inclusion of important droplet rarefaction effects; yet, it is sufficiently general such that the entire two-phase flow system can be simulated.
2. Due to finite-Kn number correction factors applied to the mass transfer and transport portions of the code, the model is valid at high gas temperatures, low gas pressures, or for small droplets, offering a wide range of conditions for which the model is applicable.
3. Different modeling options were considered for the key four aspects of the computational tool -- droplet heating, desolvation, transport, and coalescence. The research showed that the Fuks corrections should be used to model droplet heating and desolvation.
4. Comparison of exact single sphere DSMC simulations of the drag force against a sphere with different analytic slip flow models shows that the Cunningham correction applied to the Stokes' law gives the best model for droplet transport.
5. The Ashgriz-Poo model for droplet coalescence, one of the most important of the processes, was chosen based on comparisons with detailed, fundamental molecular dynamics simulations. These comparisons showed that the outcome of droplet-droplet collisions does not appear to have a temperature dependence over the range tested. The four aforementioned selections represent the baseline model recommended for the two-phase flow conditions considered here.
6. The computational tool was applied to two general classes of simulation results. A spatially uniform background gas temperature with a particle velocity distribution and a spatially variable background gas distribution corresponding to that of an ICP plasma were considered.
7. The key results for the uniform background gas are as follows. As droplet size increases, the coalescence process increases in importance. For 1µ -sized particles in a background gas of temperatures in the 1,000-2,000 K range, the Knudsen number is sufficiently large that the use of the continuum evaporation model leads to incorrect droplet evaporation rates. The simulation was also applied to the case of nebulizer droplets from a direct injection high efficiency nebulizer introduced into an inductively coupled plasma. It was found that inclusion of both coalescence and noncontinuum gas effects is also crucial to the modeling of this more complex spray system.

In the third phase activity of the side-jet modeling the following results were obtained:

(1) The interaction of a jet from a side-mounted 60~lbf thruster with the rarefied atmosphere between altitudes of 80 to 160~km has been modeled. The jet-atmospheric interaction structure showed significant changes for variations of the free stream altitude from 80 to 160 ~km. At 80~km, the flowfield exhibits continuum-like features such as an oblique shock wave and a normal plume shock, whereas, by 120~km the shock structure is much more diffuse. At the highest altitude considered here, 160~km, the plume/atmospheric interaction shock is replaced by a much more diffuse.

(2) The spatial distribution of the NO and OH UV emission in terms of W/cm^{3}µsr was calculated for all altitudes and velocities. It was found that the NO emission falls off dramatically with free stream velocity, as is consistent with the energy of reaction threshold. Radiation from OH is also sensitive to free stream velocity, but due to the lower energy of reaction threshold a small amount of radiation can be observed even at 3 km/s. An onboard sensor would measure integrated line-of-sight radiation profiles. Hence different radiation images for different viewing geometries were simulated.

(3) It was found that the spatial distribution of the OH radiation was found to follow the jet/atmospheric interaction shock structure. The integrated line-of-sight images (W/cm^{2}µsr) are sufficiently large such that an onboard imager should be able to make meaningful measurements. Such measurements on a flight experiment would provide both useful flow modeling as well as operational information about the optical seeker environment.

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